

# NEW EVIDENCE FOR TRITON AND HELION CLUSTERING IN NUCLEI

**Afsar Abbas**

Institute of Physics  
Bhubaneswar-751005, India  
email: [afsar@iopb.res.in](mailto:afsar@iopb.res.in)

## Abstract

Normally one plots separation energies  $S_{1n}$  and  $S_{2n}$  as a function of neutron number  $N$  for a particular proton number  $Z$  or plot  $S_{1p}$  and  $S_{2p}$  as a function of  $Z$  for a particular  $N$ . Here we plot the separation energies a little differently:  $S_{1n}$  and  $S_{2n}$  as a function of  $Z$  for a particular  $N$ . The same with  $S_{1p}$  and  $S_{2p}$  as a function of  $N$  for a particular  $Z$ . A systematic study of these new plots brings out certain very interesting generic features which clearly indicate presence of triton ("t")  ${}^3_1\text{H}_2$  and helion ("h")  ${}^3_2\text{He}_1$  clustering in nuclei.

In the study of nuclear structure, separation energies have played an important role and are continuing to do so in identifying new magic numbers in recent years [1-4]. In all such studies one normally plots separation energies  $S_{1n}$  and  $S_{2n}$  as a function of neutron number  $N$  for a particular proton number  $Z$  or plot  $S_{1p}$  and  $S_{2p}$  as a function of  $Z$  for a particular  $N$ .

We plot the separation energies a little differently here. We plot  $S_{1n}$  and  $S_{2n}$  as a function of  $Z$  for a particular  $N$ . The same with  $S_{1p}$  and  $S_{2p}$  as a function of  $N$  for a particular  $Z$ . We do a systematic study of these plots for all the data available in literature at present [5]. Such plots have completely been ignored in literature. This is very unfortunate as these plots do contain huge amount of interesting and revealing information which has been missed so far. We shall show that these brings out certain very interesting generic features which as we shall find clearly indicate strong evidences of triton ("t")  ${}^3_1\text{H}_2$  and helion ("h")  ${}^3_2\text{He}_1$  clustering in nuclei

We study the whole range of data set available [5]. However as all this will take much more space than necessary for this paper, here we show a few representative plots. These are one and two neutron separation energy as a function of  $Z$  for  $N = 29$  and  $30$  as plotted in Fig 1 and 2 below. All the plots of  $S_{1n}$  and  $S_{2n}$  as a function of  $Z$  for a particular  $N$  show similar features. The same with  $S_{1p}$  and  $S_{2p}$  as a function of  $N$  for a particular  $Z$ . We do a systematic study of these plots for all the data. The features which we shall point out here are there in all the other plots. In fact we shall study here only those features which are generic of all such plots. Special studies of specific set of nuclei ( which too would be very fruitful ) shall be left for separate future studies.

Certain common features which stand out are as follows (The statements below are made in the context of the plot  $S_{1n}$  and  $S_{2n}$  as a function of  $Z$  for a particular  $N$ ):

**A.** *For all even-even  $N=Z$  nuclei there is always a pronounced larger separation energy required with respect to the lower adjoining nuclei plotted.*

**B.** *For all odd-odd  $N=Z$  nuclei there is always a pronounced larger separation energy required with respect to the lower adjoining nuclei plotted.*

**C.** *For case A when  $Z$  number is changed by one unit, the separation energy hardly changes (sometimes not at all). But when this number is changed*

by two units, another pronounced peak occurs.

**D.** For case **B** when  $Z$  number is changed by one unit, the separation energy hardly changes (sometimes not at all). But when this number is changed by two units, another pronounced peak occurs. So there are peaks for odd-odd  $N-Z$  nuclei ( and not for even-even cases ).

Note that for example here we are plotting  $S_{1n}$  and  $S_{2n}$  as a function of  $Z$  for a particular  $N$ . Hence while we are pulling one or two  $N$  we are studying this as function of  $Z$ . Thus the above effects cannot be the result of identical nucleon pairings, What these plots are telling us is as to what happens to last one or two neutron bindings in a nucleus as proton number changes.

Clearly the peaks as indicated in **A** above are due to the fact that the last one or two neutrons must have come from a stable alpha cluster. This is consolidated by the fact that another extra  $Z$  does not make a difference to the separation energy.

To understand observation **B** above - note that here the peaks are there for ALL odd-odd  $N=Z$  nuclei. This is an amazing fact. These odd-odd nuclei are more stable or "magic" with respect to the adjoining odd-even or even-odd nuclei. Pairing of identical nucleons cannot explain this generic feature. Neither can alpha clustering do so. Obviously it is the formation of triton-helion 'h-t' pair which can only explain this extraordinary effect. This is the minimal requirement without which one just cannot explain the generic effect indicated in 'B'. Just as alpha clustering explains the extra stability for case **A** so does the formation of 'h-t' cluster pair can only explain the data in **B**.

What I would like to emphasize here is that the above conclusion is inescapable as per the empirical information manifested in separation energy plotted in the manner indicated above. It is Nature which is forcing this conclusion upon us.

To understand observations **C** and **D** we have to undertake new empirical studies on neutron rich nuclei.

Going through the binding energy systematics of neutron rich nuclei one notices that as the number of  $\alpha$ 's increases along with the neutrons, each  ${}^4\text{He} + 2n$  pair tends to behave like a cluster of two  ${}^3_1\text{H}_2$  nucleon [6]. Hence the author had concluded that all light neutron rich nuclei  ${}^{3Z}_Z\text{A}_{2Z}$  are made up of  $Z$  number of  ${}^3_1\text{H}_2$  clusters. There are good empirical evidence for this.

Separation energy studies like above support this conclusion too [7]. We

plotted separation energies for neutron number  $N$  and for proton number  $Z$  fixed separately at 4, 6, 8, 10, 11, 12, 16, 20, 22 and 24. We found extraordinary stability manifested by the plotted data for the proton and neutron pairs  $(Z,N)$ : (6,12), (8,16), (10,20), (11,22) and (12,24). These new magicities were present in the neutron rich sector for the pair  $(Z,N)$  where  $N=2Z$ .

What is the significance of this extraordinary stability or magicity for all the nuclei  ${}^{3Z}_{Z}A_{2Z}$ ? Quite clearly the only way we can explain the extra magicity for these  $N=2Z$  nuclei is by invoking the significance of triton clustering in the ground state of these neutron rich nuclei. So the nucleus  ${}^{3Z}_{Z}A_{2Z}$  is made up of  $Z$  number of triton clusters.

To understand this unique feature the author introduced a new symmetry "nuso-spin" symmetry [7]. Though the thrust of this paper is not this nuso-spin symmetry, the author would like to emphasize that triton and helion clustering effects in nuclei can be understood naturally in the framework of the new nuso-spin symmetry.

So it is clear that it is tritons which explain the stability of neutron rich nuclei and it is a pair of 'h-t' clusters which explain the stability of odd-odd  $N=Z$  nuclei in the separation energy as plotted above.

Now we can explain the observation **C** above. Clearly for even-even  $N=Z$  nuclei it is one ( or more ) alpha clusters which explain the data. Hence one extra  $Z$  does not affect the separation energy. But two extra  $Z$  will tend to make a pair of helions ( akin to the two tritons for neutron rich case above ). These two 'h-h' will make for the extra stability for the adjoining even-even nuclei (and so on). So also can the observation **D** be understood as the extra  $2Z$  will create an extra helion to attach to the already existing 'h-t' pair to make for extra stability of this adjoining odd-odd nuclei. Other peaks in the above plots can be similarly explained as due to alpha or triton and helion clusters.

The author would like to emphasize that quite obviously these qualitative conclusions are inescapable and unique. This is true as there is no other way to explain the above empirical observations on the whole.

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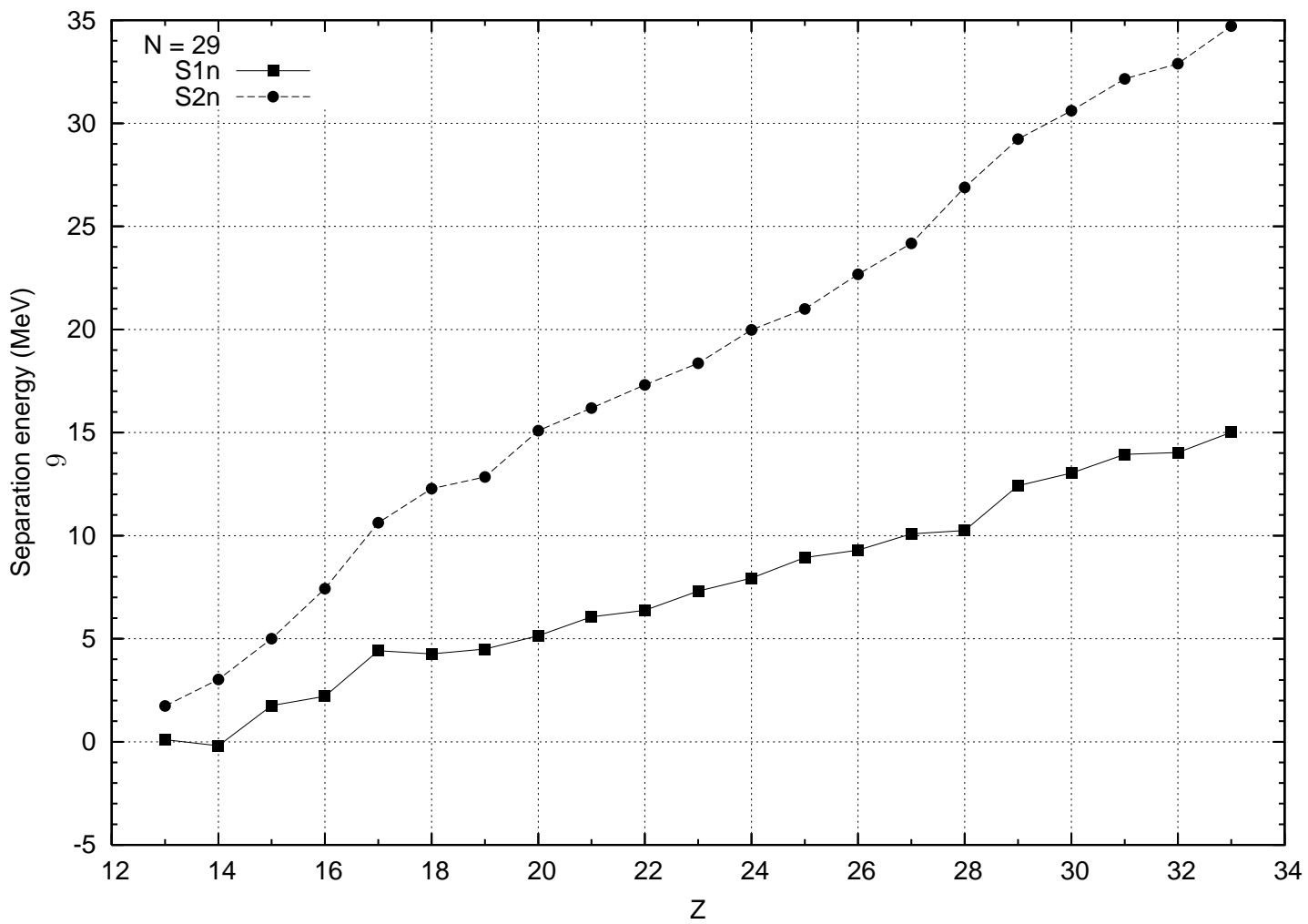


Figure 1: One and two neutron separation energy as a function of proton number  $Z$  for fixed  $N=29$  neutrons

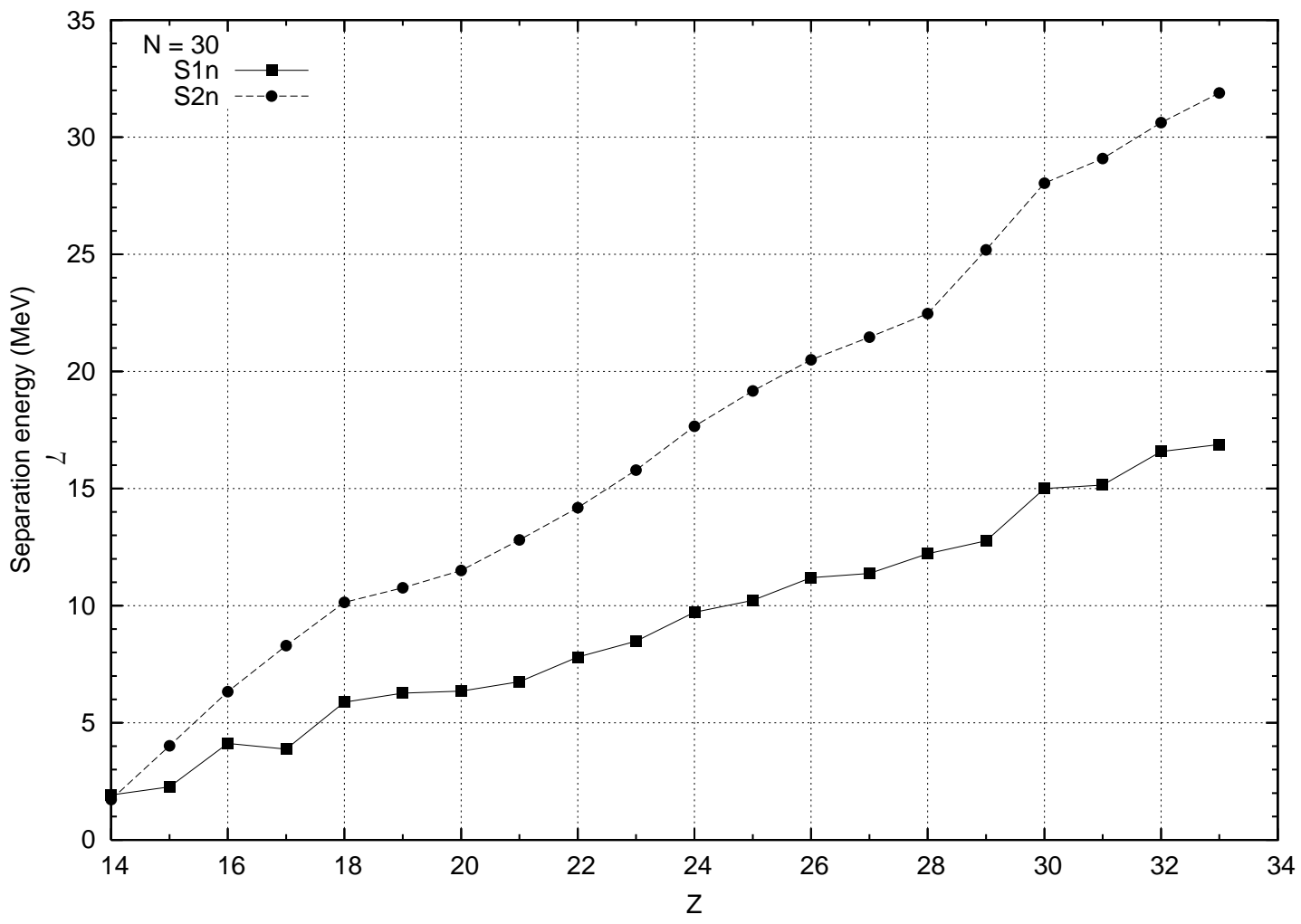


Figure 2: One and two neutron separation energy as a function of proton number Z for fixed N=30 neutrons